THE MODERN ROLE OF VISUAL OBSERVATIONS OF COMETS

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ABSTRACT. This paper reviews the role of past and future visual observations in cometary research. The strengths and limitations of visual observations are explored for the benefit of both investigators who might have to use them and observers who wish to make real contributions to the field. We consider the characteristics of the eye-brain combination as a detector and compare them with modem detectors. We specifically evaluate visual discoveries, magnitude estimates, and drawings.

1. INTRODUCTION

Modem remote sensing of comets relies upon objective electronic and photographic detectors to quantify their reflected and emitted radiation. There are, however, a few situations where contemporary or historical visual observations are used in the study of comets. We identify three main areas where visual observations may contribute to cometary studies: 1) discoveries resulting from visual searches, 2) monitoring of general cometary activity through visual brightness estimates, and 3) mostly pre-photographic era observations of coma morphology. Although most investigators today prefer the objective and quantitative data obtained with electronic detectors, there are some situations when the eye is the most convenient or only detector available. Interpretation of visual observations requires consideration of the response characteristics and interpretive abilities of the eye/brain in correlating them with other types of observations. We review the advantages and limitations of visual observations and cite examples of their use in modern cometary research. Although we try to refrain from making distinctions between professional and amateur astronomers, it should be noted that visual observations from the 19th century were made mostly by professionals, while recent visual observations are made almost exclusively by amateurs. We find that the primary advantage of current visual observations lies in the fact that there are many observers with moderate aperture telescopes with a wide geographical distribution able to observe when the major observatories are clouded out or devoted to other pursuits.

It is beyond the scope of this paper to discuss all of the details of observing techniques and analysis of the data; these are usually well covered in the cited references.

2. HISTORICAL PERSPECTIVE

There is a rich historical tradition of visual observations of comets starting with the era when the eye was the only detector. It was from this time that cometary phenomena were first being characterized and many of the fundamental concepts of cometary processes were first identified.

2.1. DISCOVERIES

Prior to the first photographic discovery of Comet P/Barnard 3 in 1892, all comets were discovered visually with the naked eye or with the aid of a telescope. Documented naked eye discoveries go back as far as 1095 B.C. (Ho Peng Yoke, 1962), and the Chinese alone document a mean rate of 20 comet apparitions per century (Kresak, 1982). Documented multiple naked-eye comet discoveries began in medieval times with Toscanelli, who drafted Columbus' map, and apparently found 1457 I and possibly 1457 II and 1472 (Vsekhsvyatskii, 1958).

Although the first telescopically discovered comet was found by Gottfried Kirsch as early as November 14, 1680 (Kronk, 1984), this was an accident as he was observing the Moon and Mars when he first saw the comet. It appears that Charles Messier was the frost to discover comets as part of a systematic program. Since his first discovery took place on January 26, 1760, (Marsden, 1986) one can speculate that his program was inspired by his observations of Comet Halley in 1758 and 1759. In any event, Messier is credited with discovering 12 comets and as he developed the concept of comet hunting as an organized activity he also compiled his famous catalog of nonstellar objects. In England, Caroline Herschel discovered her first of 8 comets in 1786. The prolific French comet discoverer Jean Louis Pens discovered the first of 37 comets in 1801. In the United States, E. E. Barnard discovered 16 comets, the last of which was also the first comet to be found photographically. More recently, visual comet discoveries are being made mostly in Japan, Australia and the United States. We should note that multiple visual discoveries are being made by only a handful of observers carrying out persistent systematic surveys.

2.2. MAGNITUDE ESTIMATES

Visual magnitude estimates go back 100 years and after astrometry provide the longest baseline of comet data available (Green and Morris, 1987). It is this extensive database that argues for continued visual brightness estimates. The total visual brightness of a comet is in some way a measure of the comet's activity, and brightness curves have been constructed to characterize their activity 'as a function of heliocentric distance. This is usually done in terms of an absolute total magnitude and a heliocentric brightness variation exponent n (for example, see Roemer, 1976 and Meisel and Morns, 1976). In some well observed comets, both variables may change over different segments of their orbits. A list of compilations of the standard brightness parameters can be found in Green et al. (1986). For comets well observed over ranges of geocentric and heliocentric distances, these brightness parameters may be useful in predicting the appearance comets in future apparitions. Most of the total visual magnitude estimates have been compiled into the archive of the International Comet Quarterly (ICQ) (Green et al.,1986). With nearly 30,000 entries of which most are visual (Green, private communication, 1989), it is the largest and most comprehensive database of such observations.

2.3. COMA MORPHOLOGY

Pre-photography visual drawings from the past provide information on the rare "great" comets that often showed much changing detail in their dust comae. A classic example is the work of F.W. Bessel who in 1835 observed material being ejected towards the sun from Comet P/Halley and formulated the concept of the "fountain" model of dust ejection from a solid nucleus. G.P. Bond's drawings of Comet Donati in 1858 showed expanding envelopes consistent with the fountain model. Other drawings of P/Halley from the 1835-36 apparition by H. Schwabe, F.G.W. Struve, J.F.W. Herschel and T. Maclear (see

Dorm et al., 1986) show many of the jets and envelope morphology which even today may provide constraints on the nucleus spin vector for that epoch.

3. THE EYE AS DETECTOR

As for any astronomical observation, correct interpretation requires an understanding of the photometric response of the detector and any reduction or translational biases. The eye-brain combination is a remarkable sensing system which varies among individuals according to age and other factors, and like other senses can be trained to respond significantly better than the average. Such training, usually obtained through experience at the telescope, can improve substantially the individual's perception of faint objects or of small features glimpsed during a moment of good seeing. Visual perception, affected in varying degrees by the physical and emotional state of the observer, is an inherently subjective process subject to statistical probabilities. As such, it may be difficult to establish uncertainties for a particular observation. Out of necessity, astronomers from the pre-photography era were more highly trained to see and record details seen through the eyepiece. Today there are many amateur astronomer with highly developed observing skills. The general characteristics of the eye as described below refer to a "normal" eye, and it should be understood that there may be significant variations. In the remainder of this review, "eye" refers to the "eye-brain combination".

3.1. SPECTRAL SENSITIVITY

Through natural selection, the spectral sensitivity of the eye in daylight (photopic) peaks near the solar intensity maximum at 555nm and drops to the 10% level at 470nm and 650nm. The peak of the dark adapted (scotopic) eye is shifted to 5 10nm (called the Purkinje shift) and is therefore most representative of the observer's eye response. Comparing this to the spectrum of a "typical" comet (fig. 1), it is clear that the eye is seeing

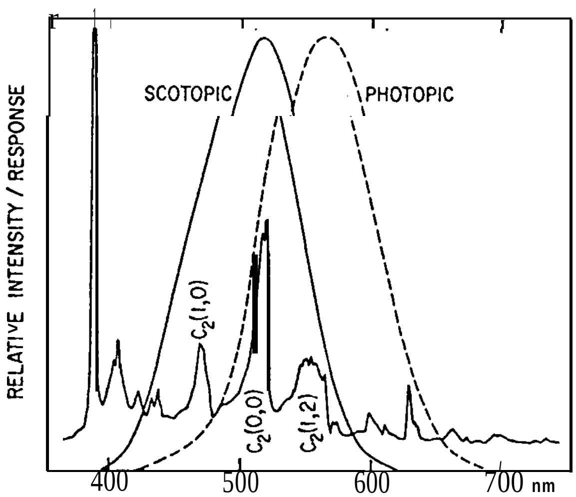

Fig. 1 The spectral sensitivity of the photopic and scotopic eye compared with the emissions of a "typical" comet. The relative contributions of the diatonic carbon and reflected solar continuum will vary according to the dust to gas ratio of the comet.

a combination of reflected solar continuum from dust and major emissions from the (O-O) and (l-2) C_2 Swan bands. Contributions from NH_2, Na and CO^+ may also be seen, but will be minor compared to C_2 and continuum. Because of the difference in apparent scale lengths of the dust and gas, a predominantly gaseous comet will appear visually less condensed than a predominantly dusty one. When a comet's heliocentric distance is greater than about 2.5 AU, the C_2 emission is usually not present, so the visual observer is seeing reflected solar continuum. For well observed comets, it should not be surprising to see an increase in the rate of pre-perihelion brightening at the onset of the C_2 emission.

3.2. DYNAMIC RANGE

The eye is sensitive to a wide range of intensities due, in a minor way, to the mechanical action of the iris in bright light, and more importantly, to pigments in the rods and cones in dim light. Most eyes can change their threshold sensitivity by some four orders of magnitude over thirty minutes of dark adaptation. The rate of change is governed first by cone adaptation, then by rods. The greater density of rods around the sides of the retina make "averted" vision a useful method for threshold detection. Dark adaptation is improved by increasing the available oxygen, and decreased by such things as vitamin A deficiency. Especially at high elevation sites, an augmented oxygen supply is most helpful in improving visual sensitivity.

In spite of its high sensitivity, the "integration constant" of the eye is about 0.07 seconds, so it cannot match the faint detection capabilities of photographic emulsions or electronic detectors that can collect light over long exposures.

3.3. RESOLUTION

As for any optical system, the eye is subject to resolution-limiting aberrations, Conditioning (mental compensation) effectively minimizes chromatic aberration, field curvature and distortion, but spherical aberration may be a factor in dark conditions, Resolution may be reduced by 20% over the four decades of brightness above threshold and may be partly responsible for star groupings (asterisms) being mistaken for a comet.

3.4. CONTRAST THRESHOLD

Blackwell (1946) showed empirically that visual contrast threshold decreases by some two orders of magnitude over the sensitivity range of the eye. Everhart (1967) demonstrated that these threshold levels help define the optimum magnification so that the affect of aperture is only to change the angular size of the comet image. The small angular size of some faint comets may prevent discovery by visual means.

3.5 PERCEPTION AND EXPERIENCE

Seeing and recognizing faint and small objects is improved through experience. The better observers are generally those who have spent much time looking through telescopes, especially when familiar with their particular optical configurations. Training allows the observer to recognise faint or low contrast features that the average person might have difficulty seeing. Well known visual observers, such as E.E. Barnard, had a very highly developed sense of visual perception with the telescope. Today, few professional astronomers spend any time looking through an eyepiece, while many amateurs have highly developed skills detecting faint and/or tiny objects through the telescope. Unfortunately, there will always be a few visual amateur astronomers who maybe influenced by peer pressure or visions of fame to see something they think they should be able to see, or very much want to see. Evaluating marginal observations may be very difficult, even when the observer attempts to be as objective as possible.

Additional information on the characteristics of vision can be found in reviews such as Fry (1965) and Williams and Becklund (1972).

4. VISUAL COMET DISCOVERIES

Today, visual comet discoveries account for roughly one-forth of all comet discoveries. In general, visual discoveries are made when a comet is inside the Earth's orbit giving solar elongations less than 90 degrees. This is due to the fact that comets are bright enough for visual detection when inside 1 AU, and since the rate of brightening can be very rapid, discovery favors the diligent, systematic visual survey. The statistics are enhanced by the fact that because the chances of visual discovery are better within 100 degrees of the Sun, more time is spent in that area. Occasionally, comets are discovered visually at high solar elongations, but only because they are close to the Earth. Kresak (1982) reviews the observational selection effects for both visual and photographic discoveries, which are particularly important in estimating the comet population distribution.

Visual searches have several advantages over equivalent photographic ones. The trained eye, scanning through a wide field eyepiece can cover some 400 square degrees an hour. With a 0.4 meter telescope, this reaches extended objects with a total magnitude of about 12. With smaller apertures and correspondingly larger fields, the time is shorter, but the brightness limit will be lower. The visual search maybe improved by using both eyes through binoculars or a double telescope system, but binocular eyepieces sharing the same input beam with beamsplitters tend to be less efficient for threshold objects. The other advantage is the immediate feedback in identifying a suspect and then trying to observe motion.

The primary disadvantage of visual surveys is the bright magnitude limit compared to photographic surveys. Another disadvantage is that the observer must either become extremely familiar with the locations of background nebulae, or frequently consult maps and charts. Another problem is that once something is identified, determination of its location may not be of particularly high precision, especially if the sky is brightening and reference stars become invisible, or the object is setting behind a landscape feature. This can be overcome by mounting a small camera with fast film and a fast lens to the telescope, and taking a short, unguided exposure of the suspect. It may not have a strong image of the suspect, or any trace of it at all if the location of the eyepiece center is known relative to brighter stars recorded in the field, but it would enable more precise astrometry. There are several schemes for sweeping which are usually dictated by mechanical constraints of the telescope or an the observer's preference. Some observers buildup a raster scan of barely overlapping fields sweeping in right ascension, declination, azimuth or elevation, while a few others systematically search boundaries of areas hoping that a comet will pass through their border field.

Statistical studies of visual comet discoveries (Everhart, 1967; Machholz, 198?); Rudenko, unpublished) show an asymmetry favoring morning discoveries. This is most apparent for elongations 35-600, and has been attributed to the orbital motion of the Earth (Kresak, 1982).

In any case, it is apparent that the most successful visual discovers are the ones who persist in searching and build up experience in recognizing threshold suspects.

5. BRIGHTNESS ESTIMATES

After astrometry, total visual magnitude estimates comprise the largest body of data available on comets. Largely supplanted today by aperture and CCD photometry with spectrally selective filters that quantify production rates of several species and dust, they still remain useful in monitoring cometary activity as a funtion of heliocentric distance and studying secular variations over many orbits. In some discussions (Marsden and Roemer, 1982) total visual magnitude estimates refer to the head and the tail. In most recent work, they refer to the total integrated brightness of the head only (Green and Morris, 1986). In cases of small phase angles, there might be an unknown contribution of a well-developed tail in the line-of-sight of the head, but this is not common.

Estimating a comet's brightness is not as simple as it may seem, The brightness profile of the extended image of a comet can vary from an almost uniform blob to a very condensed, almost starlike shape. A technique for comparing the total brightness of an extended comet with point-like stars of known brightness was first developed by Bobrovnikoff(1941) in which a comparison star and the comet are racked out of focus in an attempt to compare their surface brightnesses. Unfortunately, this meant that the comet would also be out of focus, but at least both'could be quickly compared. Sidgwick (1955) introduced the method of placing the star out of focus until its surface brightness matches the average in-focus comet surface brightness from memory. This allows estimating fainter comets which would be invisible when out of focus. Beyer (1 952) used a method of comparing the extinction of grossly out of focus images of the comet and star against the sky background. Morris (1979) introduced a method of placing both the star and comet out of focus by different amounts to better normalize their appearance. Each of these methods suffer from systematic errors of varying degrees due to the character of the comet, the observing conditions (mostly sky brightness), and the optics used (Roemer, 1976; Meisel and Morris, 1976 and 1982).

There is considerable debate on quantifying the effects of observer experience, aperture, observing methods, degree of condensation and observing conditions. The recent well observed apparitions of Comets P/Giacobini-Zinner and P/Halley provide well sampled examples of the capabilities of visual magnitude estimates (Edberg and Morris, 1986; Bouma, 1987; Edberg, 1988). Edberg has analyzed some 1000 observations of P/Giacobini-Zinner archived by the International Halley Watch and found that there was typically a two magnitude scatter (fig. 2). Analysis of the data showed that 1) more experienced observers report brighter values and have less scatter, 2) aperture correction did not reduce the scatter, but did introduce a slight zero offset, 3) there was very large scatter in estimating the coma diameter and degree of condensation. One could conclude that the discrepancy in coma diameter may reflect varying sky conditions and/or optical configurations which would also affect the magnitude estimates. A similar analysis is being conducted on the much larger P/Halley estimates, but a preliminary report using only eight days (Edberg and Morris, 1986) also show that the scatter was a function (in order of importance) of experience, coma morphology and instrumentation.

One use of visual total magnitude estimates is that they can be compared to earlier estimates to look for secular changes. Old brightness estimates have been used to predict future brightness and activity levels when there were no other data available. Newbum and others (Newburn, 1979, 1981; Newbum and Yeomans, 1982, Divine, et al., 1986) made extensive use of the visual magnitude estimates of P/Halley to estimate production rates and the spacecraft flyby environments in 1986.

One potential advantage of visual brightness estimates is that there are many observers well distributed in longitude and, in principle, more likely to identify rapid changes of activity. Such work can be particularly useful in alerting others of unusual activity, However, changes in brightness due to increased short term dust production, such as jets becoming active as they rotate into sunlight, may not appear to change significantly the total magnitude of a comet because they may constitute a small fraction of the total light of the coma, and dust jets may take days to dissipate by radiation pressure into the tail. Comet Halley's 7.4 day periodic light curve is much more easily seen with small diaphragms close to the central condensation than when integrated over the whole coma. This, coupled with the intrinsic scatter of visual estimates, makes it very difficult to identify the 7.4 day periodicity in the visual light curve (fig. 3). With less active comets, such as P/Schwassmann-Wachmann 1, eruptive episodes may occur infrequently enough so that they have substantial effect on the total brightness. In fact, "outbursts" of this comet have often been reported first by visual observers.

A major disadvantage of visual magnitude estimates is that they have a typical scatter of 0.4 magnitudes (Green and Morris, 1987). The most important problem in using visual total magnitude estimates is that they refer to unknown relative contributions of continuum and C2 emission and are difficult, if not impossible, to interpret in quantitative physical terms (Fischer and Huttemeister, 1987).

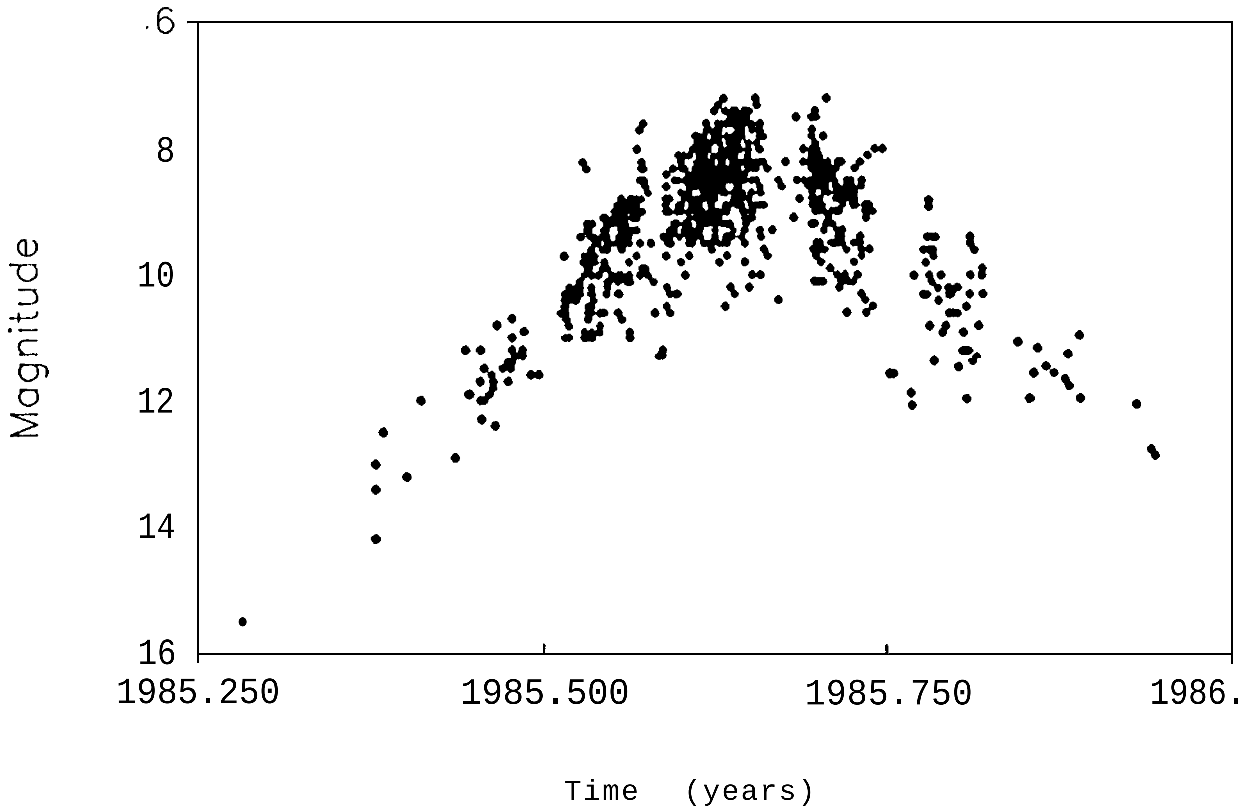

Fig. 2 Over 1000 estimates of the total visual magnitude of P/Giacobini-Zinner during nine months in 1985 as compiled by S. Edberg as part of the International Halley watch.

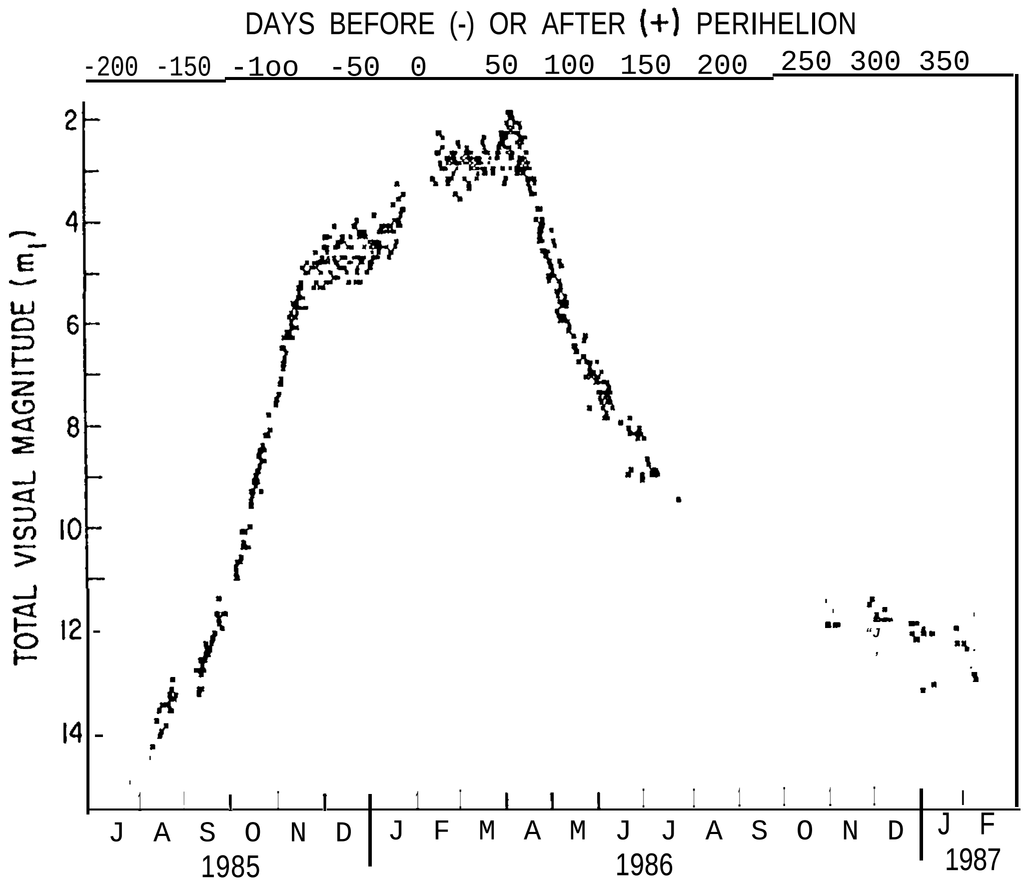

Fig. 3. The total visual magnitude of P/Halley adapted from Green and Morris (1987) showing the scatter from a statistically significant sample.

6. VISUAL DRAWINGS

Since the eye can detect low contrast and small features in the telescope, it has the potential for recording changes in coma morphology that can be used to make inferences about the rotation state of the nucleus (Sekanina, 1989). Unfortunately, most visual observers today have not developed the drawing skills nor micrometer techniques to portray accurately what they see through the eyepiece. Visual drawings are more likely to be used by someone other than the observer, so it is imortant that they be interpretable. Recent drawings made of Comet Halley provide a good opportunity to evaluate their usefulness in the context of past apparitions as well as recent CCD imagery. In general, they do not fare well. The principal problem is that rarely do observers use aids such as filar micrometers or eyepiece retitles to measure position angles and sizes of features, For observers of past apparitions of Comet Halley such techniques were common practice.

The other problem is one of interpreting different drawing “styles”. They range from fairly realistic to very abstract and schematic. Almost all observers will tend to exaggerate

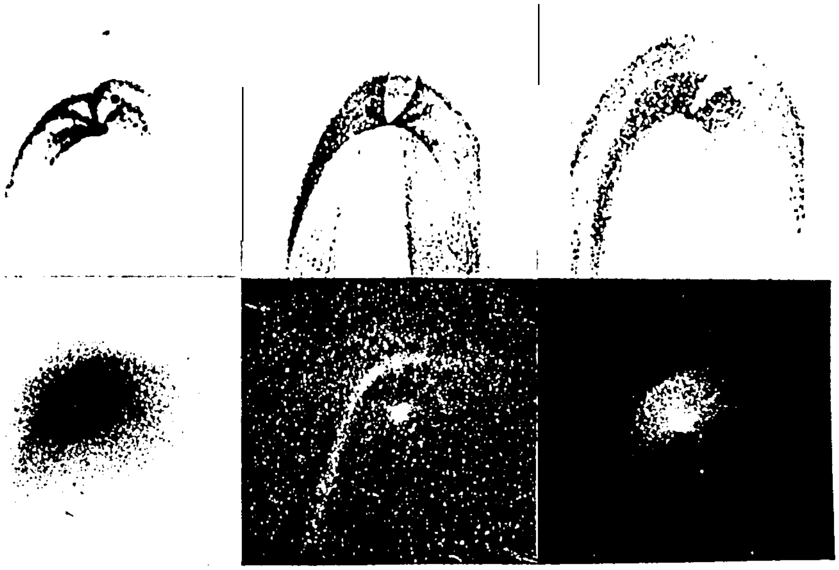

Fig. 4. Examples of styles in drawings of P/Halley by (left to right) A. Ricco, R. Innes and W.Worssell compared to straight negative, edge enhanced, and straight positive photograph by C. Lampland at the Lowell Observatory on 1910 May 21.3. The scale and orientation (sun up) are approximately normalized.

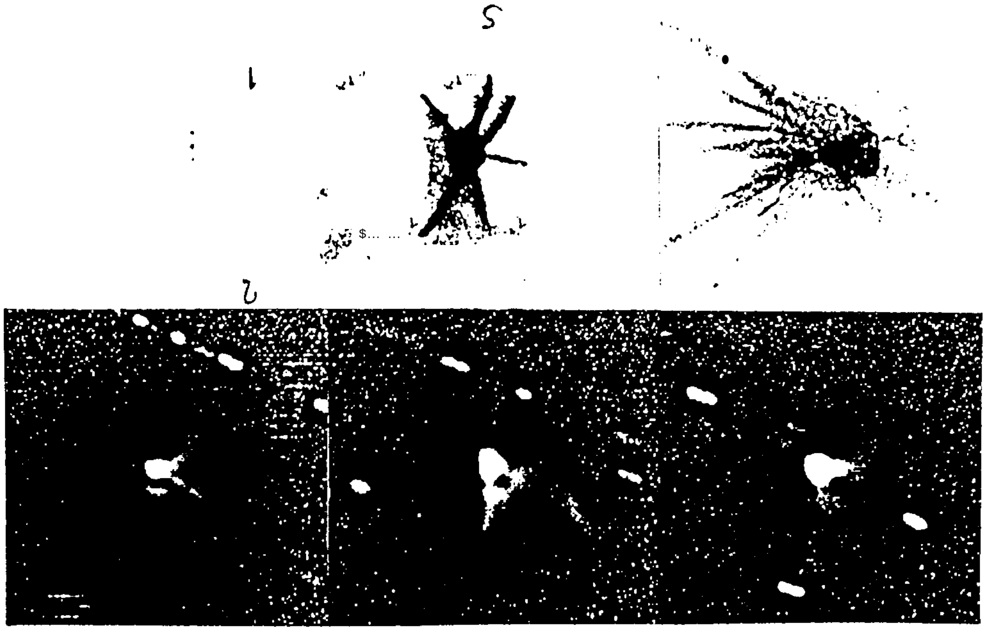

Fig. 5. Examples of drawings of P/Halley by A. Peres with the 0.7m Meudon observatory refractor on 1986 Dec. 15.9 UT (left) and S. O'Meara with the 0.2m Harvard College Observatory refractor (right) and enhanced CCD images taken with the 1.5m Catalina Observatory reflector by S. Larson and D. Levy on December 15.2, 16.2 and 17.2,1985. The scale and orientation (North up, East to the left) is approximately normalized.

the contrast of local features while ignoring the larger, lower frequency gradients in the coma. Such "spatial filtering", although photometrically inaccurate, is an advantage of visual observing. Enhancement of digital CCD images to show coma features attempts to do the same thing. Figures 4 and 5 illustrate variations in drawing styles in 1910 and 1985.

Current investigators have found some drawings to be useful in finding nucleus rotation solutions constrained by the dust emission pattern. One good example is Sekanina's study of P/Swift-Tuttle (1981), where totally independent drawings by Bond and Winnecke displayed a high degree of consistency which suggest that they could be used with a relatively hugh degree of confidence. This is not always the case as one can see by comparing drawings of P/Halley in 1910 by Innes, Worssell and Ricco at about the same time on May 21,1910 (fig. 4). Sekanina has used Baldet's drawings of P/Pens-Winnecke and P/Schwassmann-Wachmann 3 in studying the fan-shaped comae when those comets were close to the Earth (Sekanina, 1989).

7. FUTURE ROLE OF VISUAL OBSERVATIONS OF COMETS

7.1 VISUAL DISCOVERIES

Visual searches will continue to play a role finding comets, especially those which brighten rapidly near the Sun. Although possible in principle, photographic or electronic comet searches in practice do not cover the whole sky every day, or employ the army of people necessary to extract and follow up suspects. The efficiency with which the trained visual observer with good weather can search large areas and rapidly verify suspects guarantees that a significant fraction of new discoveries will be made visually. It should be noted, however, that systematic photographic surveys, such as that of the Shoemakers at Palomar, have reduced the percentage of visual discoveries from about 50% to 25% in the last 10 years. The efficiency of IRAS in discovering comets in the early 1980s has had an affect on discovery statistics. Future plans for groundbased photographic and spaceborne infrared surveys would undoubtedly have a significant impact on the success of visual searches, but with the current funding limitations for such projects visual searches will remain a vital activity.

7.2 VISUAL MAGNITUDE ESTIMATES

Visual total magnitude estimates will continue to be made because they can be compared with old observations, and because they can be made easily by a large number of observers. However, as electronic detectors and filters become less expensive and more readily available, more high precision photometric data will be obtained. The application of inexpensive CCD systems and plate scales appropriate to show the whole comet will provide interesting results such as production rates.

For visual observations, improvements can be made now by establishing a better standard for magnifications and/or apertures used. The estimates and application of the degree of condensation might be investigated to understand why there is such a disparity between observers. Because of the large number of observers, identification of short term increases of brightness (outbursts) will continue to be useful. The editors and contributes of the International Comet Quarter] y and its database of magnitudes will continue to characterize the gross brightness behavior of many comets and serve as a source of confirmation of unusual activity aiding the interpretion of other datasets.

7.3 DRAWINGS

As in the past, historical visual drawings will be used in critical situations when there is no other information. For the most part, however, modem drawings do not provide the information required for quantitative analysis. This may be due to the fact that today observers rarely use their drawings for any detailed study themselves, and therefore can not appreciate the need to go through the additional trouble of, for example, making position angle and distance measurements. The proliferation of larger apertures on precision mountings and good area detectors from hypersensitized photographic emulsions to CCD cameras, make it possible to obtain systematic records of coma and tail morphologies that are 'suited for quantitative analysis with relatively little effort With ever increasing numbers of competent astrophotographers available, most visual drawings may become products of recreational astronomy.

7,4 A FURTHER NOTE

Although outside the intended scope of this paper, we note that the role of future visual observations as contributions to cometary research will depend upon how well the observer understands and executes the needs of the scientific method. In spite of efforts to channel amateur resources in the International Halley Watch (Edberg, 1983), Edberg noted that "Many experienced amateur observers had difficulty in maintaining an unbiased, scientific attitude about their results and their methods in obtaining them... The amateur community, as a group, does not have a good understanding of the scientific method . .." (Edberg, 1987). This result of the IHW's experience with amateur astronomers may be a manifestation of the current de-emphasis of serious science education, a lack of professional involvement in fostering professional/amateur coordination, unreasonable expectations from a hobby, or some combination of these. It is clear, though, that with a serious effort, amateurs can make useful and important contributions.

The many serious amateurs eager to make contributions to cometary research constitutes a sizable resource whose potential is only partly realized. The work of a few of the leading amateurs can serve as models to encourage the thoughtful acquisition of data and the study of cometary phenomena by others with telescopes at good sites.

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